

APPLICATION
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TITLE: NOVEL GUANOSINE TRIPHOSPHATE (GTP) BINDING
PROTEIN-COUPLED RECEPTOR PROTEINS

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NOVEL GUANOSINE TRIPHOSPHATE (GTP) BINDING PROTEIN-COUPLED RECEPTOR PROTEINS

This application is a continuation-in-part of PCT/JP99/07280, filed December 24, 1999, which claims priority from PCT/JP98/05967, filed December 25, 1998, and Japanese Application No. 11/145661, filed May 25, 1999.

TECHNICAL FIELD

5 The present invention relates to novel guanosine triphosphate binding protein-coupled receptor proteins, DNA encoding the proteins, and methods of screening for drug-candidate compounds using them.

BACKGROUND ART

10 Many hormones and neurotransmitters regulate physiological functions through specific receptor proteins located on the cell membrane. Many of these receptor-proteins transduce signals into the cell by activating a guanosine triphosphate binding protein (occasionally referred to as "G protein" below) that is coupled to them. These receptor proteins are thereby named as G protein-coupled receptors. Since they have a common structure, composed of seven transmembrane regions, they are also generally called "seven-
15 transmembrane receptor proteins."

 G protein-coupled receptors, which are expressed on the surface of cells *in vivo* and functioning cells of tissues, play an extremely important role as a target of molecules such as hormones, neurotransmitters, and biologically active compounds, which regulate the functions of these cells and tissues. Therefore, G protein-coupled receptor proteins have
20 received great attention as targets in drug-development.

 G protein-coupled receptors reported so far include: muscarinic acetylcholine receptors M1, M2, M3, and M4 (Peralta et al., EMBO J., 6:3923-3929 (1987)), muscarinic acetylcholine receptor M5 (Bonner et al., Neuron, 1:403-410 (1988)), adenosine receptor A1 (Libert et al., Science, 244:569-572 (1989)), α 1A adrenoreceptor (Bruno et al., Biochem.

Biophys. Res. Commun., 179:1485-1490 (1991)), β_1 adrenoreceptor (Friele et al., Proc. Natl. Acad. Sci. USA, 84:7920-7924 (1987)), angiotensin receptor AT₁ (Takayanagi et al., Biochem. Biophys. Res. Commun., 183:910-916 (1992)), endothelin receptor ETA (Adachi et al., Biochem. Biophys. Res. Commun., 180:1265-1272 (1991)), gonadotropin releasing factor receptor (Kaker et al., Biochem. Biophys. Res. Commun., 189:289-295 (1992)), histamine receptor H₂ (Ruat et al., Proc. Natl. Acad. Sci. USA, 87:1658-1672 (1992)), neuropeptide Y receptor Y1 (Larhammar et al., J. Biol. Chem., 267:10935-10938 (1992)), interleukin-8 receptor IL8RA (Holmes et al., Science, 256:1278-1280 (1991)), dopamine receptor D₁ (Mahan et al., Proc. Natl. Acad. Sci. USA, 87:2196-2200 (1990)), metabolic glutamate receptor mGluR1 (Masu et al., Nature, 349:760-765 (1991)), and somatostatin receptor SS₁ (Yamada et al., Proc. Natl. Acad. Sci. USA, 89:251-255) (for reference, Watson S. and Arkinstall S., The G protein Linked Receptor FactsBook, Academic Press (1994)). Examples of developed medicines aimed at G protein-coupled receptors are: terazosine hydrochloride (antihypertensive agent, α_1 adrenoreceptor antagonist), atenolol (antiarrhythmia, β_1 adrenoreceptor antagonist), dicyclomine hydrochloride (antispasmodic agent, acetylcholine receptor antagonist), ranitidine hydrochloride (drug for peptic ulcers, histamine receptor H₂ antagonist), trazodone hydrochloride (antidepressant, serotonin receptor 5-HT_{1B} antagonist), and buprenorphine hydrochloride (analgesic agent, opioid receptor κ agonist) (for reference, Stadel et al., Trends Pharm. Sci., 18:430-437 (1997); Medicine Handbook 5th edition, Yakugyo-Jiho).

The hypothalamus, a part of the brain which governs a number of programs that trigger a particular response, contributes to the homeostasis of the internal environment by means of a variety of outputs, as the center of the autonomic nervous system. For instance, it releases hormones such as thyrotropic hormone-releasing hormone, gonadotropic hormone-releasing hormone, and growth hormone-releasing hormone, and thereby regulates the entire endocrine system through the actions of these hormones on the specific receptors expressed in target cells. These outputs in the hypothalamus are thought to be mediated by receptors expressed in the hypothalamus and compounds reacting with them. Therefore, elucidation of the relationship between the compounds regulating the hypothalamus outputs and their specific receptors expressed in the hypothalamus is extremely important in developing novel medicines for the treatment of diseases arising from endocrine disorders.

DISCLOSURE OF THE INVENTION

The present invention provides a novel human-derived G protein-coupled receptor protein and rat-derived one corresponding thereto, both of which are expressed in the brain (in particular, thalamus and hypothalamus, etc.). It also provides a method of screening for
5 ligands and drug-candidate compounds using these receptor proteins.

The inventors first selected a region highly conserved in known G protein-coupled receptor proteins, then designed primers corresponding to the region, and performed reverse transcriptase- polymerase chain reaction (RT-PCR) using mRNA obtained from rat thalamus and hypothalamus. Next, amplified clones were randomly selected, and their
10 partial nucleotide sequences were determined. To remove known clones from the nucleotide sequence determined-clones, colony-hybridization was performed using, as a probe, cDNA clones judged by homology search to be encoding a known G protein-coupled receptor protein. Negative clones that failed to hybridize with any probe were selected. Using probes prepared based on the nucleotide sequence of the negative clones, the inventors screened
15 cDNA libraries from rat thalamus and hypothalamus, and succeeded in isolating a full-length cDNA (rat BG2 cDNA) encoding a rat G protein-coupled receptor.

Moreover, the present inventors screened human hippocampus libraries using specific probes and successfully isolated a human cDNA (human BG2 cDNA) corresponding to the rat cDNA.

To identify a ligand for the G protein-coupled receptor protein encoded by the
20 isolated human BG2 cDNA, the present inventors prepared cells expressing the protein and stimulated the protein to screen compounds which changed the concentration of cAMP in the cells. As a result, histamine was found to have an activity of stimulating the human G protein-coupled receptor protein expressed on the cell surface and lowering the intracellular
25 cAMP concentration. In addition, histamine was found to have an activity of actually binding to the protein.

The present inventors also isolated a cDNA encoding an alternative splicing variant for rat BG2 (rat BG2-2 cDNA), expressed the protein encoded by the cDNA on a cell surface, and detected the response against the histamine stimulation, to find that the protein
30 had an activity of reducing the intracellular cAMP concentration in response to the histamine stimulation in the same manner as in human BG2.

The G protein-coupled receptor protein found by the present inventors is a very useful tool in screening for agonists and antagonists thereof, and the agonists and antagonists isolated by the screening are expected to be used as pharmaceuticals.

The present invention relates to novel human- and rat-derived G protein-coupled receptor proteins, DNAs encoding them, and screening of ligands and drug-candidate compounds using the proteins.

Specifically, the invention relates to:

(1) a guanosine triphosphate-binding protein-coupled receptor protein comprising the amino acid sequence selected from the group consisting of:

(a) the amino acid sequence of SEQ ID NO:20 or 25, and
(b) the amino acid sequence of SEQ ID NO:20 or 25, in which one or more amino acids are replaced, deleted, or added;

(2) the protein of (1), wherein the protein has an activity of binding to histamine;

(3) the protein of (1), wherein the protein has an activity of changing the intracellular cAMP concentration or calcium concentration in response to histamine stimulation;

(4) a partial peptide of the receptor protein of any one of (1) to (3);

(5) a DNA encoding the receptor protein of any one of (1) to (3) or the partial peptide of (4);

(6) the DNA of (5), wherein the DNA comprises a coding region of the nucleotide sequence of SEQ ID NO:21 or 26;

(7) a vector containing the DNA of (5) or (6);

(8) a transformant carrying the DNA of (5) or (6) or the vector of (7);

(9) a method for producing the receptor protein of any one of (1) to (3) or the partial peptide of (4), the method comprising the steps of culturing the transformant of (8) and recovering the protein or peptide from the transformant or its culture supernatant;

(10) a method of screening for a ligand which binds to the receptor protein of any one of (1) to (3), or an analogue thereof, the method comprising the steps of:

(a) exposing a test compound to the receptor protein of any one of (1) to (3) or the partial peptide of (4), and

(b) selecting the compound that binds to the protein or partial peptide;

(11) a method of screening for a compound that inhibits the binding between the receptor protein of any one of (1) to (3) and its ligand or an analogue of the ligand, the method comprising the steps of:

(a) exposing a ligand or its analogue to the receptor protein of any one of (1) to (3) or the partial peptide of (4) in the presence of a test compound, and detecting the binding activity between the protein or partial peptide and the ligand or its analogue, and

(b) comparing the binding activity detected in (a) with that in the absence of the test compound, and selecting the compound that reduces the binding activity;

(12) the method of (11), wherein the ligand is histamine;

(13) a method of screening for a compound which inhibits or promotes the activity of the receptor protein of any one of (1) to (3), the method comprising the steps of:

(a) exposing a ligand for the protein or an analogue thereof to cells expressing the protein in the presence of a test compound,

(b) detecting a change in cells associated with the binding of the protein to the ligand or the analogue thereof, and

(c) selecting a compound which inhibits or promotes the change in the cells detected in (b) in comparison with the change in the cells in the absence of the test compound;

(14) the method of (13), wherein the ligand is histamine;

(15) the method of (13) or (14), wherein the change in cells to be detected is selected from the group consisting of a change in cAMP concentration, a change in calcium concentration, an activation of G protein, an activation of phospholipase C, and a change in pH;

(16) a kit for the method of any one of (10) to (15), the kit comprising the receptor protein of any one of (1) to (3) or the partial peptide of (4);

(17) an antibody which binds to the receptor protein of any one of (1) to (3);

(18) a compound isolated by the method of any one of (11) to (15); and

(19) a pharmaceutical composition comprising the compound of (18) as an active ingredient.

“G protein-coupled receptor protein” herein refers to a receptor protein that transduces intracellular signals by activating G proteins.

“Ligand” refers to a natural compound capable of binding to a G protein-coupled receptor and inducing signal transduction. “Analogue of a ligand” herein refers to a derivative of the ligand having the same physiological activity as the ligand binding to a G protein-coupled receptor protein, or inhibiting a physiological activity of the ligand, and contains both natural and artificially synthesized compounds. For example, histamine and R(-)- α -methylhistamine correspond to a ligand and an analogue thereof, respectively.

“Agonist” refers to a compound having a bioactivity similar to that of the ligands of G protein-coupled receptors, including both natural and artificially synthesized compounds.

“Antagonist” refers to a compound capable of inhibiting the bioactivity of a ligand of a G protein-coupled receptor, including both natural and artificially synthesized compounds.

“Protein” and “peptide” as used herein include their salts as well.

An “isolated nucleic acid” is a nucleic acid, the structure of which is not identical to that of any naturally occurring nucleic acid or to that of any fragment of a naturally occurring genomic nucleic acid spanning more than three genes. The term therefore covers, for example, (a) a DNA which has the sequence of part of a naturally occurring genomic DNA molecule but is not flanked by both of the coding sequences that flank that part of the molecule in the genome of the organism in which it naturally occurs; (b) a nucleic acid incorporated into a vector or into the genomic DNA of a prokaryote or eukaryote in a manner such that the resulting molecule is not identical to any naturally occurring vector or genomic DNA; (c) a separate molecule such as a cDNA, a genomic fragment, a fragment produced by polymerase chain reaction (PCR), or a restriction fragment; and (d) a recombinant nucleotide sequence that is part of a hybrid gene, i.e., a gene encoding a fusion protein. Specifically excluded from this definition are nucleic acids present in mixtures of different DNA molecules, transfected cells, or cell clones, e.g., as these occur in a DNA library such as a cDNA or genomic DNA library.

The term “substantially pure” as used herein in reference to a given polypeptide means that the polypeptide is substantially free from other biological macromolecules. For example, the substantially pure polypeptide is at least 75%, 80, 85, 95, or 99%) pure by dry weight. Purity can be measured by any appropriate standard method known in the art, for example, by column chromatography, polyacrylamide gel electrophoresis, or HPLC analysis.

A "conservative amino acid substitution" is one in which an amino acid residue is replaced with another residue having a chemically similar side chain. Families of amino acid residues having similar side chains have been defined in the art. These families include amino acids with basic side chains (e.g., lysine, arginine, histidine), acidic side chains (e.g., aspartic acid, glutamic acid), uncharged polar side chains (e.g., glycine, asparagine, glutamine, serine, threonine, tyrosine, cysteine), nonpolar side chains (e.g., alanine, valine, leucine, isoleucine, proline, phenylalanine, methionine, tryptophan), beta-branched side chains (e.g., threonine, valine, isoleucine) and aromatic side chains (e.g., tyrosine, phenylalanine, tryptophan, histidine).

The present invention provides novel G protein-coupled receptor proteins derived from human and rat. The nucleotide sequence of the cDNA encoding human G protein-coupled receptor (human BG2) isolated herein is shown in SEQ ID NO:21, and the amino acid sequence of the human BG2 protein is shown in SEQ ID NO:20. The nucleotide sequence of the cDNA encoding rat G protein-coupled receptor (rat BG2-2) isolated in the present invention is shown in SEQ ID NO:26, and the amino acid sequence of the rat BG2-2 protein is shown in SEQ ID NO:25.

Human BG2 protein has 32%, 28%, and 27% homology to known G protein-coupled receptors, namely human α -2C-1 adrenoreceptor (Regan et al., Proc. Natl. Acad. Sci. USA, 85:6301-6305 (1988)), mouse β -1 adrenoreceptor (Jasper et al., Biochim. Biophys. Acta., 1178:307-309 (1993)), and human muscarinic acetylcholine receptor M3 protein (Peralta et al., EMBO J., 6:3923-3929 (1987)), respectively. These results suggest that the human BG2 proteins belong to the G protein-coupled receptor family. Furthermore, this suggests that they participate in signal transduction through the activation of G proteins upon ligand binding. In fact, human BG2 protein has an activity of binding to histamine, and of reducing the intracellular cAMP concentration in response to the stimulation by histamine. Human BG2 protein of the present invention was expressed in the brain (for example, hippocampus). In brain, hippocampus plays an important role in memory and learning, the cerebellum regulates the body motions, and the hypothalamus serves as the center of the autonomic nervous system. Thus, the human BG2 proteins are assumed to be involved in the regulation of these functions. Therefore, the proteins and genes, or an agonist or antagonist that can regulate the human BG2 protein function(s), can be used in the treatment of disabilities in

memory and learning, or the control of the autonomous nervous system, such as regulation of blood pressure, digestion, body temperature, food-intake, etc. In addition, rat BG2-2 protein is a rat protein corresponding to human BG2 protein and is, like human BG2 protein, a G protein-coupled receptor protein whose ligand is histamine.

5 The proteins of the present invention may be prepared as natural proteins, and also as recombinant proteins, by using recombinant DNA technology. A natural protein may be prepared, for instance, by extracting tissues, speculated to express the protein of the present invention, and performing immunoaffinity chromatography using antibody as described later on. On the other hand, a recombinant protein can be prepared by culturing transformant cells
10 carrying DNA encoding the protein of the present invention as described later on. One skilled in the art can prepare an altered protein having a function or an activity (transduction of intracellular signals through G protein activation, binding activity to histamine, and activity of varying concentration of intracellular cAMP or calcium responded by histamine stimulation) equivalent to that of the natural protein by introducing modifications such as
15 replacement of any amino acid contained in the natural protein of the present invention (SEQ ID NO:20 or SEQ ID NO:25) according to known methods. Mutations of amino acids in a protein may occur naturally. The G protein-coupled receptor proteins of the present invention include such mutant proteins having an amino acid sequence altered by replacement, deletion or addition, having a function equivalent to that of the natural protein.
20 The methods of altering amino acids, known to one skilled in the art, include, the Kunkel method (Kunkel et al., Methods Enzymol., 154:367-382 (1987)), double primer method (Zoller et al., Methods Enzymol., 154:329-350 (1987)), cassette mutation (Wells et al., Gene, 34:315-323 (1985)), and megaprimer method (Sarkar et al., Biotechniques, 8:404-407 (1990)). The number of mutated amino acids in a functionally equivalent protein is generally
25 not more than 10% of all the amino acids, preferably not more than 10 amino acids, and more preferably not more than 3 amino acids (for instance, one amino acid).

 The invention also includes a polypeptide, or fragment thereof, that differs from the corresponding sequence shown as SEQ ID NO:20 or SEQ ID NO:25. The differences are, preferably, differences or changes at a non-essential residue or a conservative substitution.
30 In one embodiment, the polypeptide includes an amino acid sequence at least about 60% identical to a sequence shown as SEQ ID NO:20 or SEQ ID NO:25, or a fragment thereof.

Preferably, the polypeptide is at least 65%, 70%, 75%, 80%, 85%, 90%, 95%, 98%, 99% or more identical to SEQ ID NO:20 or SEQ ID NO:25 and has at least one G-protein coupled receptor protein function or activity described herein. Preferred polypeptide fragments of the invention are at least 10%, preferably at least 20%, 30%, 40%, 50%, 60%, 70%, or more, of the length of the sequence shown as SEQ ID NO:20 or SEQ ID NO:25 and have at least one G-protein coupled receptor protein activity described herein. Or alternatively, the fragment can be merely an immunogenic fragment.

As used herein, "% identity" of two amino acid sequences, or of two nucleic acid sequences, is determined using the algorithm of Karlin and Altschul (PNAS USA, 87:2264-2268, 1990), modified as in Karlin and Altschul, PNAS USA, 90:5873-5877, 1993). Such an algorithm is incorporated into the NBLAST and XBLAST programs of Altschul et al. (J. Mol. Biol., 215:403-410, 1990). BLAST nucleotide searches are performed with the NBLAST program, score = 100, wordlength = 12. BLAST protein searches are performed with the XBLAST program, score = 50, wordlength = 3. To obtain gapped alignment for comparison purposes GappedBLAST is utilized as described in Altschul et al (Nucleic Acids Res., 25:3389-3402, 1997). When utilizing BLAST and GappedBLAST programs the default parameters of the respective programs (e.g., XBLAST and NBLAST) are used to obtain nucleotide sequences homologous to a nucleic acid molecule of the invention.

The present invention also includes partial peptides of the above-described G protein-coupled receptor proteins. The partial peptides of the present invention include, for instance, those corresponding to the N-terminal region of the G protein-coupled receptor protein, which can be utilized to prepare an antibody. Moreover, partial peptides of the present invention include peptides having the binding activity to histamine and peptides having an activity of changing the intracellular cAMP concentration or calcium concentration in response to the stimulation by histamine when expressed on the cell surface. These peptides can be used for screening drug-candidate compounds as described below. Moreover, a partial peptide which has the binding activity to histamine but does not have an activity of conducting the signal transduction into cells, can be a competitive inhibitor for the proteins of the present invention. Such partial peptides of the invention usually have a length of at least 15 amino acids, and preferably 20 amino acids or more.

Furthermore, the present invention provides DNA encoding the proteins of the invention as described above or partial peptides thereof. The DNA encoding the protein of the invention or partial peptide thereof include cDNA, genomic DNA, and synthetic DNA, but are not so limited as long as they encode the proteins or the peptides. cDNA encoding the proteins of the present invention can be screened by labeling, with ^{32}P or the like, for example, the cDNA as described in SEQ ID NO:21 or NO:26, a part of it, complementary RNA to the DNA, or a synthetic oligonucleotide comprising a part of the cDNA and by hybridizing them to a cDNA library from a tissue expressing the protein of the present invention (for instance, brain tissue). Alternatively, cDNA may be cloned by synthesizing an oligonucleotide corresponding to the nucleotide sequence of the cDNA, and amplifying cDNA from an appropriate tissue (such as brain tissue) by PCR. Genomic DNA can be obtained by screening a genomic library by hybridization using, as a ^{32}P -labeled probe, the cDNA as described in SEQ ID NO:21 or NO:26, or a part of it, complementary RNA to the DNA, or a synthetic oligonucleotide comprising a part of the cDNA. Alternatively, it may be cloned by synthesizing an oligonucleotide corresponding to the nucleotide sequence of the cDNA, and amplifying genomic DNA by PCR. Synthetic DNA can be prepared by chemically synthesizing oligonucleotides comprising a part of the nucleotide sequence of SEQ ID NO:21 or NO:26, annealing them into a double strand, and ligating them using DNA ligase (Khorana et al., J. Biol. Chem., 251:565-570 (1976); Goeddel et al., Proc. Natl. Acad. Sci. USA, 76:106-110 (1979)).

In one aspect, the invention provides an isolated or purified nucleic acid molecule that encodes a polypeptide described herein or a fragment thereof. Preferably, the isolated nucleic acid molecule includes a nucleotide sequence that is at least 60% identical to the nucleotide sequence shown in SEQ ID NO:21 or SEQ ID NO:26. More preferably, the isolated nucleic acid molecule is at least 65%, 70%, 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more, identical to the nucleotide sequence shown in SEQ ID NO:21 or SEQ ID NO:26. In the case of an isolated nucleic acid molecule which is longer than or equivalent in length to the reference sequence, *e.g.*, SEQ ID NO:21 or SEQ ID NO:26, the comparison is made with the full length of the reference sequence.

Where the isolated nucleic acid molecule is shorter than the reference sequence, *e.g.*, shorter

than SEQ ID NO:21 or SEQ ID NO:26, the comparison is made to a segment of the reference sequence of the same length (excluding any loop required by the homology calculation).

The invention also includes nucleic acid sequences that hybridize to the nucleic acid molecule shown as SEQ ID NO:21 or SEQ ID NO:26, or a fragment thereof. Hybridization
5 is performed in 6X SSC, 40% formamide at 25°C, followed by a wash in 1X SSC at 55°C (low stringency); in 6X SSC, 40% formamide at 37°C, followed by a wash in 0.2X SSC at 55°C (medium stringency); or in 6X SSC, 40% formamide at 37°C, followed by a wash in 0.1X SSC at 62°C (high stringency).

These DNA can be used for producing recombinant proteins. Namely, it is possible
10 to prepare the protein of the invention as a recombinant protein by inserting a DNA encoding the receptor protein (DNA as described in SEQ ID NO:21 or NO:26, for instance) into an appropriate expression vector, culturing a transformant obtained by introducing the vector into an appropriate cell, and purifying the expressed protein. Since the protein of the invention is a receptor protein, it is possible to prepare it in a form expressed on the cell
15 membrane.

Specifically, if the host is *Escherichia coli*, the plasmid vectors such as pET-3 (Rosenburg et al., Gene, 56:125-135 (1987)) and pGEX-1 (Smith et al., Gene, 67:31-40 (1988)) may be used. *E. coli* can be transformed by the Hanahan method (Hanahan D., J. Mol. Biol., 166:557-580 (1983)), electroporation (Dower et al., Nucleic Acids Res., 16:6127-
20 6145 (1988)), and such. If the host is fission yeast (*Schizosaccharomyces pombe*), a plasmid vector such as pESP-1 (Lu et al., Gene, 200:135-144 (1997)) may be used. Yeast can be transformed by spheroplast fusion (Beach et al., Nature, 290:140 (1981)), lithium acetate method (Okazaki et al., Nucleic Acids Res., 18:6485-6489 (1990)), etc.

If the host is a mammalian cell, such as Chinese Hamster ovary-derived (CHO) cells
25 and human HeLa cells, vectors such as pMSG (Clontech) may be used. Recombinant DNA may be introduced into mammalian cells by calcium phosphate method (Graham et al., Virology, 52:456-467 (1973)), DEAE-dextran method (Sussman et al., Mol. Cell. Biol., 4:1641-1643 (1984)), lipofection (Felgner et al., Proc. Natl. Acad. Sci. USA, 84:7413-7417 (1987)), electroporation (Neumann et al., EMBO J., 1:841-845 (1982)), etc. If the host is an
30 insect cell, a baculovirus vector such as pBacPAK8/9 (Clontech) can be used.

Transformation of insect cells is done by the methods described in the literature (Bio/Technology 6:47-55 (1980)).

Recombinant proteins expressed in host cells can be purified by known methods. The proteins can also be synthesized as fusion proteins tagged with histidine residues at the N-terminus, or fused to glutathione-S-transferase (GST), and purified by using their binding ability toward a metal chelating resin, or a GST affinity resin (Smith et al., J. Biol. Chem., 263:7211-7215 (1988)), respectively. For instance, when the vector pESP-1 is used, the protein of interest is synthesized as a fusion protein with GST, which can be purified using GST affinity resin. The fusion protein may be digested with thrombin, or blood coagulating factor Xa to liberate the protein of interest.

Moreover, DNA encoding the proteins of the present invention can be used in gene therapy of diseases that arise from a mutation of the protein. When used in gene therapy, the DNA can be introduced into human cells using retrovirus vectors (Danos et al., Proc. Natl. Acad. Sci. USA, 85:6460-6464 (1988); Dranoff et al., Proc. Natl. Acad. Sci. USA, 90:3539-3543 (1993)), adenovirus vectors (Wickham et al., Cell, 73:309-319 (1993)), etc. To administer the vector to patients, transplantation of bone marrow, subcutaneous injection, and intravenous injection can be used (Asano S., Protein Nucleic acid and Enzyme, 40:2491-2495 (1995)).

Furthermore, the present invention provides antibodies capable of binding to the proteins of the invention. Antibodies against the proteins can be prepared by known methods in the art (for instance, refer to Shin-Seikagaku-Jikken-Kouza I: Protein I 389-406, Tokyo-Kagaku-Doujin). For instance, polyclonal antibodies are prepared as follows. An appropriate dose of the above proteins or partial peptides thereof are administered into immune animals such as rabbits, guinea pigs, mice, or chickens. Administration may be performed together with an adjuvant (such as FIA or FCA) that promotes antibody production, and usually performed every couple of weeks. The titer of antibodies can be increased by performing multiple immunizations. After the final immunization, antisera are obtained by withdrawing blood from immune animals. Polyclonal antibodies are purified from antisera by ammonium sulfate precipitation, fractionation by anion exchange chromatography, or affinity chromatography with either Protein A or immobilized antigen. Monoclonal antibodies are prepared as follows. The proteins of the invention or partial

peptides thereof are administered into immune animals as described above. After the final immunization, their spleens or lymph nodes are excised. Then, antigen-producing cells are recovered from the spleens or the lymph nodes, and fused with myeloma cells using polyethylene glycol and such to produce hybridomas. Desired hybridomas are selected by screening, and their culture supernatant is used to prepare monoclonal antibodies.

Monoclonal antibodies can be purified by ammonium sulfate precipitation, fractionation by anion exchange chromatography, or affinity chromatography with either Protein A or immobilized antigen. Antibodies prepared thereby can be used not only in affinity purification of the protein of the invention, but also for the diagnosis or antibody treatment of diseases arising from the abnormal expression of the receptors, or detection of the expression level of the receptors.

If used for antibody treatment, humanized antibodies or human antibodies are preferable. Humanized antibodies, in case of mouse-human chimeric antibodies, are prepared by isolating the gene encoding the antibody against the G protein-coupled receptor protein from the producing mouse cells, replacing the constant region of the H chain of the antibody with that of the human IgE, and introducing it into mouse myeloma J558L cells (Neuberger et al., Nature, 314:268-270 (1985)). Human antibodies can be prepared by immunizing mice, whose immune system is replaced with that of human, with the protein.

Furthermore, the present invention provides a method of screening for ligands or their analogues of the protein of the invention. The methods include such processes as exposing a test compound to the G protein-coupled receptor protein or its partial peptide, and selecting compounds that are capable of binding to the proteins or the peptide. Compounds to be tested include compounds or their analogues such as acetylcholine, adenosine, adrenaline, noradrenaline, angiotensin, bombesin, bradykinin, C5a anaphylatoxin, calcitonin, cannabinoids, chemokines, cholecystokinin, dopamine, endothelin, formylmethionylpeptide, GABA, galanin, glucagon, glutamate, glycopeptide hormone, histamine, 5-hydroxytryptophan, leucotriene, melanocortin, neuropeptide Y, neurotensin, odorant, opioid peptide, opsin, parathyroid hormone, platelet activating factor, prostanoid, somatostatin, tachykinin, thrombin, thyrotropin releasing hormone, vasopressin, and oxytocin (Watson S. and Arkinstall S., G protein Linked Receptor FactsBook, Academic Press (1994)), and also other purified proteins, expressed products of genes (including libraries),

extracts of tissues or cells in which the ligand is stipulated to be expressed (the brain, thalamus, and hypothalamus etc.), and the culture medium of the cells. The proteins may be used in a form expressed in desired cells (including transformants genetically engineered to express the proteins) or on the cell surface, in the form of the membrane fractions of the cells, or in a form bound to an affinity column. If necessary, test compounds may be labeled appropriately. Methods for labeling include radioisotope labeling, and fluorescence labeling, but are not limited thereto. The binding between the proteins and test compounds can be examined by detecting the label added to the compound (for instance, measuring the radioactivity or fluorescence intensity), or using as an index, intracellular signaling triggered by the compound binding to the protein (such as G protein activation, the change in the concentration of Ca^{2+} or cAMP, phospholipase C activation, and the change in pH). Specific methods can be employed as described in the literatures (Cell Calcium, 14:663-671 (1993); Analytical Biochemistry, 226:349-354 (1995); J. Biol. Chem., 268:5957-5964 (1993); Cell, 92:573-585 (1998); Nature, 393:272-273 (1998)), and unexamined published Japanese patent application (JP-A) No. Hei 9-268. Alternatively, the binding may be detected by measuring the activity of a reporter gene using two-hybrid system (Zervos et al., Cell, 72:223-232 (1994); Fritz et al., Nature, 376:530-533 (1995)).

The present invention also provides a method of screening for a compound which can inhibit the binding between the proteins of the invention and their ligands or their analogues. The method includes the steps of (a) exposing the ligand or its analogue to the proteins of the present invention or their partial peptides in the presence of a test compound, and detecting the binding activity between the proteins or partial peptides and the ligand or its analogue, and (b) comparing the binding activity detected in (a) with that in the absence of the test compound, and selecting a compound that reduces the binding activity. Compounds to be tested include proteins, peptides, non-peptide compounds, artificially synthesized compounds, extracts of tissues and cells, sera, but are not limited thereto. The proteins may be used in a form expressed in desired cells (including transformants genetically engineered to express the proteins) or on the cell surface, in a form of the membrane fractions of the cells, or in a form bound to an affinity column. If necessary, ligands may be labeled appropriately. Methods for labeling include radioisotope labeling, and fluorescence labeling,

but are not limited thereto. As a ligand, for example, histamine can be preferably used. An analogue of histamine, for example, R(-)- α -methylhistamine, can be used.

The binding activity between the proteins of the present invention or their partial peptides and ligands or their analogues can be examined by detecting a label added to the ligand or its analogue (for instance, measuring the radioactivity or fluorescence intensity), or using cellular change, as an index, that are triggered by the compound binding to the protein (such as G protein activation, the change in the concentration of Ca^{2+} or cAMP, phospholipase C activation, and the change in pH). Specific methods can be employed by the method of Zlokarmik et al. (Science, 1998, 279:84) as described in examples. Moreover, the methods can be employed as described in the literatures (Cell Calcium, 14:663-671 (1993); Analytical Biochemistry, 226:349-354 (1995); J. Biol. Chem., 268:5957-5964 (1993); Cell, 92:573-585 (1998); Nature, 393:272-273 (1998)), and JP-A No. Hei 9-268). If the results of the detection show that the binding activity in the presence of a test compound is lower than that in the absence of the compound (control), the compound is judged to be capable of inhibiting the binding between the proteins or their partial peptides and the ligands or their analogues. These compounds include those capable of triggering the intracellular signaling through binding to the protein (agonist), and those not having such activity (antagonist). Agonists have similar bioactivities to those of the ligands of the proteins. On the other hand, antagonists inhibit the bioactivities of the ligands. Therefore, these agonists and antagonists are useful as medicinal compositions for treatment of diseases arising from disorders in the signaling pathway mediated by the proteins.

In addition, the present invention provides a method of screening for a compound which inhibits or promotes an activity of the protein of the present invention. The screening method contains the steps of (a) exposing a ligand for the protein or an analogue thereof to cells expressing the protein in the presence of a test compound, (b) detecting a change in cells associated with the binding of the protein to the ligand or the analogue thereof, and (c) selecting a compound which inhibits or promotes the change in the cells detected in (b) in comparison with the change in the cells in the absence of the test compound. Compounds to be tested include proteins, peptides, non-peptide compounds, artificially synthesized compounds, extracts of tissues and cells, and sera, but are not limited thereto. A compound isolated by the screening in which the inhibition of the above binding activity is an index can

be used as a test compound. Cells which express the proteins of the present invention can be prepared by, for example, inserting a DNA encoding the proteins to an appropriate vector, and introducing the vector into an appropriate animal cell, as described in Example 5. Into the expression vector, a marker gene for selecting a recombinant may be inserted. As a
5 ligand for stimulating the proteins of the present invention, for example, histamine can be preferably used. An analogue of histamine, for example, R(-)- α -methylhistamine, can be used.

A change in cells associated with the binding of a ligand or an analogue thereof to the proteins of the present invention can be detected, for example, using, as an index, an
10 activation of G protein, a concentration change of Ca^{2+} or cAMP, an activation of phospholipase C, a change of pH. Specific methods can be employed by the method of Zlokarmik et al. (Science, 1998, 279:84) as described in Example 6. Moreover, the methods can be employed as described in the literatures (Cell Calcium, 14:663-671 (1993); Analytical Biochemistry, 226:349-354 (1995); J. Biol. Chem., 268:5957-5964 (1993); Cell, 92:573-585
15 (1998); Nature, 393:272-273 (1998)), and JP-A No. Hei 9-268).

As a result of this detection, when a test compound used inhibits a change in cells in comparison with that in cells in case of reacting a ligand or an analogue thereof in the absence of the test compound, the used test compound is judged to be a compound which inhibits an activity of the proteins of the present invention. In contrast, when a test
20 compound enhances a change in the cells, the compound is judged to be a compound which promotes an activity of the protein of the present invention.

A compound isolated by the screening method of the present invention (an agonist or antagonist of the proteins of the present invention) can be applied to, for example, attention deficit hyperactivity disorder, Alzheimer's disease, memory disorder, dysgnosia,
25 schizophrenia, sleep disorder, insomnia, sleep-induced apnea syndrome, narcolepsy, articular rheumatism, osteoarthritis, gastric ulcer, inflammatory intestine disorder, ischemic heart disease, arrhythmia, high or low blood pressure disorder, epilepsy, obesity, cibophobia, depression, anxiety, migraine, asthma, Huntington's disease, pain, nicotine abstinence symptoms (Trends in Pharmacological Science, 19:177-183; Stark et al., Drugs of the Future
30 21:507-520 (1996); Onodera et al., Jpn J. Psychopharmacol., 15:87-102 (1995)). When using these compounds as a drug, the isolated compound itself can be directly administered to the

patient, or it can be given after formulating as pharmaceutical compositions by using commonly known pharmaceutical preparation methods. The compound may be administered after formulating by mixing with, for example, pharmaceutically acceptable carriers or media, and specifically, sterilized water, physiological saline, plant oils, emulsifiers, suspending agents, surfactants, stabilizers, binders, lubricants, sweeteners, flavors, coloring agents, and so on. The administration to patients is done by methods commonly known to those skilled in the art, such as intraarterial, intravenous, or subcutaneous injections and, in addition, intranasal, bronchial, intramuscular, or oral administrations. One skilled in the art can suitably select the dosage according to the body-weight or age of a patient, or the method of administration.

Furthermore, the present invention provides a kit for the screening described above, comprising the proteins of the present invention or their partial peptides. The proteins or their partial peptides may be in a form expressed in desired cells (including transformants genetically engineered to express the protein) or on the cell surface, in a form of membrane fractions of the cell, or in a form bound to an affinity column. Components of the kit of the invention may include, other than the above-described receptor protein samples, ligand samples (both labeled and unlabeled), and buffers for the reaction between the ligand and the receptor protein, and wash solutions. Labels to be added to the ligands include radioisotope and fluorescence, for instance. The kit of the invention can be used as described in JP-A No. Hei 9-268. Moreover, for example, in the screenings using the detection system of the cAMP concentration change described in Example 6, and the detection system of the binding activity described in Example 7, the kit of the present invention can be used.

All references and patents cited herein are incorporated by reference in their entirety.

DESCRIPTION OF DRAWINGS

Fig. 1 shows the hydrophobicity plot of the rat BG2 protein. The seven hydrophobic regions (transmembrane regions) that are characteristics of the G protein-coupled receptor proteins are indicated by the numbers from 1 to 7. The numbers in the bottom indicate those of the amino acid residues in the BG2 protein.

Fig. 2 shows the results of northern blot analysis of the tissue-specific expression of the human and rat BG2 genes.

Fig. 3 shows the results of *in situ* hybridization analysis of the location of the rat BG2 gene expression in the brain.

5 Fig. 4 shows the results of *in situ* hybridization analysis of the location of the rat BG2 gene expression in the spinal cord. "Sense" and "Antisense" indicate the results using sense RNA probe (not hybridizing with mRNA; negative control), and antisense RNA probe (hybridizing with mRNA), respectively.

10 Fig. 5 shows the results of detecting a change of cAMP concentration after reacting various drugs on human BG2-expressing cells. Intracellular cAMP concentration was increased by forskolin, an activator of adenylate cyclase (Lane: control), and a change of intracellular cAMP concentration in case of reacting various test compounds was measured (Lanes: A1 to H10) using the method of Zlokarmik et al. (Science, 1998, 279:84). A level of intracellular cAMP concentration in case of not reacting forskolin was shown in Lane: base.

15 Fig. 6 shows the results of detecting a change of cAMP concentration after reacting histamine on the cells in which rat BG2-2 or BG2 was expressed in the presence of forskolin.

DETAILED DESCRIPTION

The present invention is illustrated in detail below with reference to examples, but is not to be construed as being limited thereto.

20 Example 1: Isolation of a gene encoding a rat G protein-coupled receptor

The G protein-coupled receptors share a characteristic structure composed of seven transmembrane regions, and the amino acid sequences of the transmembrane regions and the adjacent regions are well conserved. The present inventors first compared the nucleotide
25 sequences of the second and the seventh transmembrane domains, which are highly conserved, with known G protein-coupled receptors: mouse neuropeptide Y receptor Y1 (GenBank Accession Number Z18280), rat Y1 (Z11504), human Y1 (M84755), mouse neuropeptide Y receptor Y4 (U40189), rat Y4 (Z68180), human Y4 (Z66526), and mouse neuropeptide Y receptor Y6 (U58367), and synthesized novel sense and antisense primers, as
30 described in SEQ ID NO:3 and NO:4, respectively.

Next, single stranded cDNA was synthesized from poly(A)⁺RNA prepared from rat (*Rattus norvegicus*) thalamus and hypothalamus using the RNA-PCR kit (TaKaRa), and PCR was performed using the two primers. Specifically, poly(A)⁺RNA was purified from rat thalamus and hypothalamus using Fasttrack 2.0 kit (Invitrogen). Then, 75 ng of the poly(A)⁺RNA was used to synthesize complementary DNA according to the protocol accompanying the RNA-PCR kit (TaKaRa). PCR amplification was performed using all the cDNA. The reaction mixture comprising each 0.15 mM dNTPs, 1.5 mM MgCl₂, 0.025 U/μl rTaq polymerase (TaKaRa), each of 0.5 μM degenerated primer Fg (SEQ ID NO:3) and Rb (SEQ ID NO:4), and 10x PCR buffer accompanying the enzyme was prepared making a total of 130 μl, and aliquoted into six 20-μl fractions. PCR was performed with the Pertier thermal cycler PTC200 (MJ Research) under conditions as follows: a single cycle of 94°C for 2 min, followed by 35 cycles of 94°C for 30 sec, 48°C for 1 min, 72°C for 1 min 30 sec, and then a single cycle of 72°C for 8 min. After PCR, the six reaction-solutions were combined, and the amplified products were purified using the Wizard PCR purification kit (Promega), and then eluted with 30 μl of TE. 2 μl of the TE eluate was used for cloning into the pCR2.1 vector of the TOPO TA cloning kit (Invitrogen). XL1-Blue cells were used as the host cell and transformed using the *E.coli* pulser (BioRad). From the resulting transformants, 5,760 colonies having white or light blue color were randomly selected using the gene library construction system BioPick (BioRobotics), and inoculated into fifteen 384-well plates containing LB media supplemented with 100 μg/ml ampicillin. Clones were cultured at 37°C overnight, and replica plated onto a filter on top of a LB agar plate containing 100 μg/ml ampicillin and 25% glycerol, and another filter on top of a LB agar plate containing 100 μg/ml ampicillin, for preparing a glycerol stock, and colony hybridization, respectively, using a gene library replicating system BioGrid (BioRobotics).

Since the obtained PCR clones were expected to contain multiple overlapping clones of the NPY receptor cDNA, 80 clones out of the 5,760 clones were randomly selected, and their nucleotide sequences were partially determined. To determine the nucleotide sequence, plasmid DNA purified by the plasmid automatic isolating system PI100sigma (Kurabo) was used as a template. The sequence reactions were performed using the dye-primer-cycle sequencing kit FS (Perkin Elmer), and the reaction products were separated by electrophoresis using the DNA sequencer 377 (Perkin Elmer). The homology search of the

obtained sequence using the BLAST program of the Wisconsin package (Genetic Computer Group) showed that 29 out of the 80 clones were the cDNAs encoding the coiled-coil like protein 1 (GenBank Accession Number U79024) while 17 clones were those of the neuropeptide Y receptor Y1 (Z11504). Then, these two cDNA fragments were used as a probe for hybridization with the filters containing a library of the degenerated PCR amplified fragments. Probes were prepared by amplifying the insert of the respective clones by PCR, purifying the products using the Wizard PCR purification kit (Promega), and labeling them with [α - 32 P] dCTP using the Prime-It II random primer labeling kit (Stratagene). Colony hybridization was performed according to the standard method (Sambrook et al., Molecular Cloning: A laboratory manual 2nd edition (1989)). Colonies that were negative for either the coiled-coil like protein 1 or the neuropeptide Y receptor Y1 were selected and their partial nucleotide sequences were determined. For DNA sequencing, the insert fragment of each clone was amplified by PCR from the culture medium, purified using the PCR product purification kit (Amersham), and used as a template. The sequence reactions were performed using the dye-primer-cycle sequencing kit FS (Perkin Elmer), and the reaction products were separated by electrophoresis using the DNA sequencer 377 (Perkin Elmer). The obtained sequences were analyzed by the homology search using the BLAST program of the Wisconsin package (Genetic Computer Group), and, as a result, a clone which has significant homology to the muscarinic acetylcholine receptor M5 (GeneBank Accession Number M22926) was found. The clone has been deposited at the National Institute of Bioscience and Human-Technology, Agency of Industrial Science and Technology.

Name of the depositary institution:

National Institute of Bioscience and Human-Technology, Agency of Industrial
Science and Technology, MITI.

Address of the depositary institution:

1-1-3 Higashi, Tsukuba, Ibaraki 305-8566, Japan.

Date of deposit: 12/25/1997.

Accession Number: FERM BP-6575

Next, in order to isolate the full-length cDNA of the gene, cDNA libraries were prepared from rat thalamus and hypothalamus. cDNA was synthesized according to the protocol accompanying the cDNA synthesizing kit (Stratagene), and the vector pEF1x and the host XL1-blue MRF' (Stratagene) were used.

5 The pEF1x is a refined derivative of the pcDNA3 (Invitrogen) prepared as follows.

(1) Preparation of the human EF1 α promoter (GenBank Accession Number J04617)

PCR was performed using human genomic DNA with primers (SEQ ID NO:6/
CGAGGATCCGTGAGGCTCCGGTGCCCGTC; SEQ ID NO:7/
10 CGGGTAAGCTTCACGACACCTGAAATGGAAGA). The products were digested with
BamHI (TaKaRa) and HindIII (TaKaRa), and subcloned into the plasmid vector pUC19
(TaKaRa). The resulting plasmid was digested with XhoI, blunt-ended with Klenow
fragment (TaKaRa), and self-ligated using the DNA ligation kit (TaKaRa). The resulting
plasmid was digested with BamHI and HindIII, and the insert was recovered.

15

(2) Alteration of pcDNA3

pcDNA3 was digested with MluI (TaKaRa), blunt-ended with Klenow fragment
(TaKaRa), and self-ligated using the DNA ligation kit. The resulting plasmid was digested
with AflIII (New England Biolabs) and SmaI (TaKaRa), blunt-ended with Klenow fragment
20 (TaKaRa), and self-ligated using the DNA ligation kit. Then, the obtained plasmid was
digested with BglII (TaKaRa) and HindIII, and the fragment from which the CMV promoter
was removed was recovered and ligated with the insert fragment recovered in (1) using the
DNA ligation kit to construct pEF1x.

Next, the nucleotide sequence of the cDNA fragment was used to synthesize
25 oligonucleotide probe (SEQ ID NO:8/CCTTCTGCATCCCATTTGTACGTACC). According
to the protocol of the gene trapper cDNA positive selection system (GIBCO BRL), multiple
clones were obtained from the above-prepared cDNA libraries derived from rat thalamus and
hypothalamus. Then, colony hybridization was performed using the cDNA insert of the
above-isolated clone (FERM P-16572) as a probe, and a positive clone was obtained. This
30 clone has been deposited with the National Institute of Bioscience and Human-Technology,
Agency of Industrial Science and Technology.

Name of the depositary institution:

National Institute of Bioscience and Human-Technology, Agency of Industrial
Science and Technology, MITI.

5 Address of the depositary institution:

1-1-3 Higashi, Tsukuba, Ibaraki 305-8566, Japan.

Date of deposit: 12/25/1997.

Accession Number: FERM BP-6574

10 The insert fragment of the clone was 2.7 kb long. Plasmid DNA was prepared with
the QIAprep Midi Kit (QIAGEN), and the complete nucleotide sequence was determined
using the shotgun cloning method (Sambrook et al., Molecular Cloning: A laboratory manual
2nd edition (1989)). cDNA fragmentation was performed using the closed sonifier
biomaterial treating system Biorupter (Tousou Denki), and the DNA fragments were
15 separated by electrophoresis on a 2% agarose gel. Fragments of around 0.6 kb were purified
using the gene clean spin kit (bio101), blunt-ended with T4 DNA polymerase (TaKaRa), and
cloned into HincII-BAP-treated pUC118 vector. XL1-Blue was used as a host cell, and
transformed using the *E. coli* pulser (BioRad). The obtained shotgun clones were sequenced
using the dye-primer cycle sequencing kit FS (Perkin Elmer), or the dye-terminator cycle
20 sequencing kit FS (Perkin Elmer). The resulting sequences were combined and edited to get
the complete nucleotide sequence using the DNA sequencing software Sequencher (Hitachi
Software). The complete nucleotide sequence was composed of 2700 bp, and turned out to
be encoding a protein of 413 amino acids (SEQ ID NO:5). Because there is a stop codon in
the 5' region of the open reading frame, the cDNA is presumed to include the entire coding
25 region (SEQ ID NO:2). When this sequence was translated into the amino acid sequence, the
hydrophobicity plot identified seven transmembrane regions from 1 to 7 (Figure 1).

In addition, the open reading frame size was approximately 1.2 kb, which is similar to
that of the known G protein-coupled receptors. G protein-coupled receptor proteins have
common features in their amino acid sequences, and thus form a protein family. As a result
30 of the homology search using the amino acid sequence encoded by the isolated cDNA, the
encoded protein was found to be a novel receptor protein having a homology of 26%, 25%,

and 29% to known G protein-coupled receptors: bovine muscarinic acetylcholine receptor M3 protein (Lee et al., *Biochim. Biophys. Acta*, 1223:151-154 (1994)), human muscarinic acetylcholine receptor M5 protein (Bonner et al., *Neuron*, 1:403-410 (1988)), and mouse α 2A adrenoreceptor (Link et al., *Mol. Pharmacol.*, 42:16-27 (1992)), respectively.

5

Example 2: Isolation of the human G protein-coupled receptor gene

The obtained rat sequence was subjected to EST search to reveal a fragment of the human homologue (gene bank NID: 946030 and NID: 901756). Human fetal brain cDNA was amplified by PCR using the specific primers IF01 (SEQ ID NO:9/

10

CTTCCGCCGGGCCTTCACCAA) and IR02 (SEQ ID NO:10/ACAGACACGGCGGGGCTCAC) (probe 1). A human λ EMBL3 SP6/T7 genomic library (Clontech) of a size of 1.2×10^6 pfu was screened using probe 1 according to standard plaque hybridization procedures. Two positive clones were thus isolated. The obtained phage-

15

clones were digested with SacI, and three bands of a clone were subcloned. These fragments, termed I1 (SEQ ID NO:11), I3 (SEQ ID NO:12) and I5 (SEQ ID NO:13), were sequenced and a hypothetical sequence was speculated by comparing with the rat homologue. I1 and I3 were subjected to PCR amplification using specific primers YS03 (SEQ ID NO:14/

20

TGAACGCTTCGGGGGCGCTG) and YS05 (SEQ ID NO:15/GAGATGGCGAGGTTGAGCAGG), and YS12 (SEQ ID NO:16/GGCTCCAAGCCATCGGCGTC) and YS14 (SEQ ID NO:17/CTCACTTCCAGCAGTGCTCC), respectively, and the PCR products were termed probe 2 and probe 3, respectively. Human hypothalamus cDNA (1.3×10^6 phage) was plated at a density of 5.6×10^4 pfu/150 mm plate. The obtained sub-pools were checked by PCR using the primers YS03 and YS05. One positive sub-pool was screened in the same method as the screening of the genomic library, using probe 2. One cDNA clone containing the region between 5'UTR and TM5 was obtained and named cDNA clone 1.

25

Probe 4 was amplified by PCR from cDNA clone 1 using the primers YS07 (SEQ ID NO:18/ GCCTCCGCACCCAGAACAAAC) and YS10 (SEQ ID NO:19/ TGCGCCTCTGGATGTTTCAG). Screening of the human hippocampus library (3×10^6 pfu) was done in the same method as the genomic library, using probe 3 and probe 4. A few clones were obtained and the longest one, termed cDNA clone 2, was sequenced. It has the

30

region between TM2 and 3'UTR. cDNA clone 1 was digested with SacII, and the 3.3 kb band, which contained vector and the 5'-end region, was treated by shrimp alkaline phosphatase. cDNA clone 2 was also digested with SacII, and the 1.7 kb fragment was ligated into the 3.3 kb fragment from cDNA clone 1. The clone into which this ligated
5 fragment was inserted has been deposited with the National Institute of Bioscience and Human-Technology, Agency of Industrial Science and Technology.

Name of the depositary institution:

10 National Institute of Bioscience and Human-Technology, Agency of Industrial Science and Technology, MITI.

Address of the depositary institution:

1-1-3 Higashi, Tsukuba, Ibaraki 305-8566, Japan.

Date of deposit: 12/17/1998.

Accession Number: FERM BP-6609

15 Human BG2 cDNA nucleotide sequence is shown in SEQ ID NO:21, and the amino acid sequence of the protein encoded by the cDNA in SEQ ID NO:20.

Human BG2 protein had 32%, 28%, and 27% homology to known G protein-coupled receptors: human α -2C-1 adrenoreceptor (Regan et al., Proc. Natl. Acad. Sci. USA, 85:6301-6305 (1988)), mouse β -1 adrenoreceptor (Jasper et al., Biochim. Biophys. Acta, 1178:307-309 (1993)), and human muscarinic acetylcholine receptor M3 protein (Peralta et al., EMBO J., 6:3923-3929 (1987)), respectively.

Example 3: Northern blot analysis

25 Probe 4 was labeled with ^{32}P γ -dCTP (Amersham, Prime It II) and used as cDNA probe for the detection of human BG2. Human Multiple Tissue Northern (MTN) Blots Membrane was purchased from Clontech. After prehybridization of the membrane at 68°C for 30 min in ExpressHyb solution (Clontech), it was hybridized with the probe at 68°C for 1 hr (final concentration of the probe was 1.5×10^6 cpm/ml). The blot was rinsed with
30 2x SSC containing 0.1% SDS at 42°C for 30 min, and the final wash was done at 50°C for

30 min in 0.1x SSC containing 0.1% SDS. The blot was then exposed at -80°C for 2.5 days to Kodak autoradiographic film.

For the detection of the rat BG2, probe was prepared by PCR-amplifying using the rat BG2 cDNA as a template with sense primer MF2 (SEQ ID NO:22/
5 TGCATCCCATTTGTACGTNCC) and antisense primer MR1 (SEQ ID NO:24/
TGCTCTGGGACACCATCTTC), purifying the amplified products by electrophoresis on an agarose gel, and labeling them as described above for human gene.

Blotting membrane used was Rat MTN (Multiple Tissue Northern) blot (Clontech). Hybridization was performed at 42°C overnight in hybridization buffer (50% formamide,
10 4x SSPE, 1% SDS, 0.5% BLOTTO, and 100 µg/ml salmon sperm DNA). The membrane was washed at 65°C in 0.1x SSC containing 0.1% SDS, and then exposed to the Kodak autoradiography film at -80°C overnight. The results showed that the human and rat BG2 genes are strongly expressed particularly in the brain (Fig. 2).

Example 4: *In situ* Hybridization

15 Adult male Sprague-Dawley rats (Charles River Japan) aged 13 to 18 weeks, were anesthetized with inhalation of ether, connected to a rotary pump and infused with chilled 4% paraformaldehyde in phosphate buffer (pH 7.2) via a cannula inserted into the left ventricle. After perfusion, brain, pituitary gland, and spinal cord were removed and dissected to sagittal or coronal sections. The tissue specimens were postfixed with the same fixative overnight at
20 4°C. The following process was carefully done to avoid RNase contamination. Tissue specimens were embedded in paraffin wax in a routine manner, then paraffin sections were cut into a thickness of 6 µm by rotary microtome (Model HM 355; MICROM Laborgerate GmbH). The sections were stored in moisture free condition at -20°C until proceeded to *in situ* hybridization.

25 For preparation of rat BG2 sense and antisense RNA probes, the cDNA fragment amplified by PCR from MP-21 plasmid DNA using a sense primer MF2 (SEQ ID NO:22/
TGCATCCCATTTGTACGTNCC) and antisense primer MR3 (SEQ ID NO:23/
ATCATTAGGAGCGTGTANGG) was cloned into pZER0-2 vector (Invitrogen). The RNA probes were labeled with digoxigenin using DIG RNA Labeling Kit (Boehringer Mannheim).
30 The paraffin sections were de-paraffinized with xylene and transferred to distilled water after rinsing with a graded series of ethanol. *In situ* Hybridization Reagents (ISHR, Code No.

316-01951; Nippon Gene) were used as reagents without digoxigenin-labeled RNA. The sections were incubated with two changes of phosphate buffer saline (PBS; ISHR 1) for 1 min and 10 min. The sections were treated with proteinase K (ISHR 6) for 10 min at 37°C. Acetylation was done with acetylation buffer (ISHR 3) containing acetic anhydride (ISHR 4) for 15 min, followed by quenching with PBS/glycine buffer (ISHR 2) for 20 min at room temperature. After that, the sections were rinsed twice with 4x SSC (ISHR 5) for 10 min and then rinsed with PBS buffer for 10 min. After pre-hybridization with 50% formamide/2x SSC for 30 min at room temperature, hybridization was performed for 16 hr at 42°C using digoxigenin-labeled RNA probe (1 µg/ml).

Post hybridization washing was performed twice with 50% formamide/2x SSC for 10 min at 42°C. Then, the sections were treated with RNase A (ISHR10)/NET buffer (ISHR 9) for 30 min at 37°C after rinsing with NET buffer (ISHR 9) for 5 min at 37°C. After washing twice with 0.1x SSC buffer (ISHR 11) for 20 min, the sections were transferred and the digoxigenin used for labeling was detected using the Digoxigenin Detection Kit (Boehringer Mannheim). Then, the sections were rinsed for 1 min at room temperature with buffer (Buffer 1) containing 100 mM Tris-Hcl and 150 mM NaCl and incubated with blocking reagent (Buffer 2) for 30 min at room temperature. The sections were incubated with anti-digoxigenin alkaline phosphatase-labeled antibody for 60 min at room temperature. After washing with Buffer 1 for 15 min and Buffer 3 for 2 min at room temperature, the sections were incubated with NBT/X-phosphate solution diluted with Buffer 3 for 12 to 14 hr at room temperature. The sections were mounted with glycerol or Permount after washing with Buffer 4.

As a result, as shown in Figures 3 and 4, BG2 cDNA probe was strongly hybridized to the hippocampus and the spinal cord. A medium degree of hybridization signal was also detected in hypothalamus, thalamus, and cerebellum.

Example 5: Preparation of human BG2-expressing cells

Human BG2 expression vector was prepared using pIRESneo and pIRESHyg (CLONTECH). To facilitate cloning of the human BG2 gene, a plasmid in which neomycin resistance gene of pIRESneo was replaced with a hygromycin resistance gene of pIRESHyg was prepared, and the human BG2 gene was cloned thereto to prepare the expression vector.

This human BG2 expression vector was introduced by lipofection method into HEK 293 cells in which β -lactamase gene was ligated downstream of CRE sequence (purchased from Aurora). For introducing the gene, Lipofectamine PLUS reagent (GIBCO-BRL) was used and the experimental manipulation was performed according to the attached manual.

Human BG2-expressing cells were selected by placing cells in a medium containing hygromycin, and cells which grew in the medium were used for a functional assay as human BG2-expressing cells. The expression of BG2 gene was confirmed by the RT-PCR method.

Example 6: Measurement of intracellular cAMP concentration

The intracellular cAMP concentration was measured by the method of Zlokarmik et al. (Science, 1998, 279:84). In the method of Zlokarmik et al., intracellular cAMP concentration was measured by introducing the gene in which β -lactamase gene was ligated downstream of the sequence that increased transcription activity of a gene downstream thereof dependently on the increase of intracellular cAMP concentration (CRE: cAMP responsible element), and by measuring fluorescence changes in fluorescent substrates to which an activity of β -lactamase transcribed and translated by the change of cAMP concentration in the cells was added.

Moreover, to measure the decrease of intracellular cAMP concentration mediated by the bound G protein in seven-transmembrane receptors, an activity of β -lactamase depending on the intracellular cAMP concentration was increased by adding forskolin and the decrease of cAMP in cells was measured with the decrease of β -lactamase activity when a ligand was reacted.

The cells in which the above reporter gene and human BG2 were expressed were washed with PBS(-) buffer (GIBCO-BRL) twice, Cell-dissociation buffer (GIBCO-BRL) was added thereto, and the cells were warmed at 37°C in a CO₂ incubator for 3 min and dissociated from a flask by gently tapping the incubation flask. The cells were collected by centrifugation, suspended in Opti-MEM medium (GIBCO-BRL) containing 0.1% BSA (Sigma) to count the number of cells, and adjusted to 8×10^4 cells/ml.

To 1 μ l of DMSO solution containing 100 μ g/ml of each drug, 50 μ l of Opti-MEM medium (GIBCO-BRL) containing 0.1% BSA (Sigma) to which forskolin (Sigma) was

added at a final concentration of 0.5 μ M was added in advance to prepare the reaction solution. To this reaction solution, 50 μ l of the cells adjusted to the above cell number was added to initiate the reaction, and warmed at 37°C in the CO₂ incubator for 3 hours.

Subsequently, using a kit purchased from Aurora, Solution A [1 mM CCF2-AM/dry DMSO solution], Solution B [100 mg/ml Pluronic 127, 0.1% acetic acid in DMSO], and Solution C [24% w/w PEG-400, 18% TR40, water] were mixed at a ratio of 12 μ l: 120 μ l: 2 ml to prepare a pigment introduction buffer. To the above reaction solution, 20 μ l of the pigment introduction solution was added, and placed for 1 hour at room temperature to introduce into cells a fluorescent pigment (CCF2-AM) which is a substrate for β -lactamase, and change of intracellular cAMP concentration was measured by obtaining fluorescence at fluorescence wave length 460 nm (decomposed CCF) and 530 nm (CCF) with excitation wave length 409 nm and by calculating (EM460/EM530).

Each drug was tested at the concentration of 1 μ g/ml, and in BG2-expressing cells, the ratio of EM460/EM530 reduced to 35% of the control by histamine (when the value of the ratio in the control was 100, and the value of the ratio in the absence of forskolin was 0). The same phenomenon was observed in R(-)- α -methylhistamine, imetit, and N- α -methylhistamine, which are histamine analogue agonists (Fig. 5). Specifically, intracellular cAMP concentration was decreased in BG2-expressing cells by histamine. This intracellular cAMP concentration-reducing phenomenon by histamine was a phenomenon specific to BG2-expressing cells and was not observed in control cells expressing nothing.

Other test drugs (carbachol, which is an agonist for a muscarinic acetylcholine receptor; serotonin, which is an agonist for a serotonin receptor; and dopamine, which is an agonist for a dopamine receptor, etc.) at the concentration of 1 μ g/ml did not reduce intracellular cAMP concentration. This shows that the BG2 receptor is a histamine receptor.

Table 1 below shows the compounds used in the experiment.

Table 1

	1	2	3	4	5	6	7	8	9	10
A	Albuterol hemisulfate	DSP-4 hydrochloride	Phenoxy-benzamine hydrochloride	(±)-Chlorpheniramine maleate	(-)-Epinephrine bitartrate	Histamine, 1-methyl-, dihydrochloride	Methoxamine hydrochloride	Oxymetazoline hydrochloride	Phenylephrine hydrochloride	Thioperamide maleate
B	Alprenolol hydrochloride	Benextramine tetrahydrochloride	Bretylium tosylate	(±)-CGP-12177A hydrochloride	None	Hydrochlorothiazide	(±)-Nometanephrine hydrochloride	Prazosin hydrochloride	None	Triptenamine hydrochloride
C	(±)-Alenolol	MHPG sulfate potassium	BU224 hydrochloride	Clobenpropit dihydrobromide	None	(±)-Isoproterenol hydrochloride	L(-)-Norepinephrine bitartrate	(±)-Pindobind	Protriptyline hydrochloride	S(-)-Timolol maleate
D	Agmatine sulfate	6-Fluoro-norepinephrine hydrochloride	B-HT 933 dihydrochloride	Cirazoline hydrochloride	Guanabenz acetate	p-Iodoclonidine hydrochloride	None	Prazobind	Promethazine hydrochloride	Urapidil hydrochloride
E	AGN 192403 hydrochloride	Xylamine hydrochloride	B-HT 920 dihydrochloride	CGP 20712A methanesulfonate	L-Histidine hydrochloride	ICI 118,551 hydrochloride	Nisoxetine hydrochloride	Pindolol	Ranitidine hydrochloride	UK 14,304
F	Clonidine hydrochloride	Benoxathian hydrochloride	BRL 37344 sodium	Dimaprit dihydrochloride	Histamine hydrochloride	Imetit dihydrobromide	Nylidrin hydrochloride	(±)-Propranolol hydrochloride	Rauwolfscine hydrochloride	Xylazine hydrochloride
G	p-Aminoclonidine hydrochloride	MHPG piperazine	CGS-12066A dimaleate	Diphenhydramine hydrochloride	Histamine, R(-)-alpha-methyl-, dihydrochloride	Metanephrine hydrochloride	Naltopidil dihydrochloride	Pyrilamine maleate	SKF 91488 dihydrochloride	Yohimbine hydrochloride
H	(±)-threo-DOPS	WB-4101 hydrochloride	Cimetidine	Dobutamine hydrochloride	Histamine, N alpha-methyl-, dihydrochloride	(-)-alpha-Methyl-norepinephrine	(±)-Octopamine hydrochloride	Phentolamine mesylate	Triprolidine hydrochloride	YS-035 hydrochloride

5 Example 7: Histamine binding experiment

Using R(-)- α -methylhistamine, which is a histamine analogue agonist, the binding experiment was conducted. The cells in which the BG2 receptor was expressed were washed with PBS(-) buffer (GIBCO-BRL) twice, Cell-dissociation buffer (GIBCO BRL) was added thereto, and the cells were warmed at 37°C for 3 min in a CO₂ incubator and were dissociated from the incubation flask by gently tapping the flask. The cells were collected by centrifugation, and suspended in an assay buffer (Hanks' Balanced Salt Solution [GIBCO-BRL], 10 mM Hepes [Nacalai], 0.1% BSA [Sigma], pH 7.4 [adjusted with NaOH], the number of cells were counted, and the cells were adjusted to a final concentration of 0.6x 10⁶ cells/ml. The cells were warmed at 37°C in the above assay buffer with 0.2 nM R(-)- α -methyl[imidazole-2,5(n)-3H]histamine (Amersham) for 30 min, and collected with Unifilter plate GF/B (Packard) treated with 0.5% polyethyleneimine (Wako). The nonspecific binding of the histamine analogues to cells was measured in the presence of 2 μ M R(-)- α -methylhistamine (RBI). As a result, in BG2-expressing cells, whole binding:nonspecific binding is 4.4:1, and that in the control cells which did not express BG2 is 1.2:1. Thus, there is little difference between the amount of nonspecific binding in expressing cells and that in non-expressing cells. This indicates that the BG2 receptor specifically binds to the histamine analogues.

Example 8: Isolation of rat BG2 alternative splicing variants

Using the gene trapper cDNA positive selection system of Example 1 (2) (GIBCO BRL), numerous positive clones were obtained from rat thalamus- and hypothalamus-derived cDNA libraries. The analysis of these clones by the agarose gel electrophoresis with
5 restriction enzyme decomposition and the determination of nucleotide sequences revealed that these clones contained clones different from rat BG2 (SEQ ID NO:5). Sequencing of these clones showed that these clones encode a protein composed of 445 amino acid residues, in which 32 amino acid residues were inserted into the third intracellular domain in comparison with rat BG2 (this clone was named "rat BG2-2"). The structure of BG2-2 is
10 similar to that of human BG2 and shorter than human BG2 by 8 amino acid residues at the C-terminal side. These are considered to be rat BG2 alternative splicing variants transcribed from the identical gene.

Example 9: Preparation of rat BG2-2-expressing cells (BG2-2-stable cell line)

15 HEK293-CRE-BLA cells (Aurora) were cultured using the D-MEM/F-12 (1:1) mixed medium (GIBCO BRL) containing 10% fetal calf serum and 500 µg/ml G418 at 37°C in the presence of 5% CO₂. Effectene Transfection Reagent (QIAGEN) was used for gene introduction.

A day prior to the gene introduction, cells were spread on a 6-well plate (NUNC) at
20 3×10^5 cells/well and 0.4 µg each of the rat BG-2 and BG2-2 expression vectors was introduced into them using 10 µl/well Effectene Transfection Reagent according to the attached manual. The cells were cultured at 37°C in the presence of 5% CO₂ for 48 hours.

To isolate single cells into which the target gene was introduced, the cells were detached from a Petri dish by trypsin, and spread to a 96-well plate (NUNC) at 2000 to
25 250 cells/well. The cells were further cultured in selection medium containing hygromycin at 37°C in the presence of 5% CO₂ for 14 days. Wells containing cells consisting of a single colony were only selected and cells were passage-cultured to prepare a stable cell line. From BG2-2-expressing cells prepared in this manner, total RNA was prepared and the amount of expression of the introduced BG2-2 was examined by Northern hybridization and cells with
30 high expression were used for the following experiment. As a control, rat BG2-expressing cells were prepared in the same manner.

Example 10: Measurement of intracellular cAMP concentration (ELISA method)

To measure the decrease of intracellular cAMP concentration mediated by the bound G protein in seven-transmembrane receptors, forskolin was added and intracellular cAMP concentration was measured when a ligand was reacted.

5 A day prior to the measurement of cAMP in cells, 2.5×10^4 cells/well were spread on a 24-well plate coated by poly-L-lysine (SUMIRON) and further incubated at 37°C for 24 hours. The stable cell line was incubated at 37°C for 15 min in D-MEM/F-12 (1:1) mixed medium free from serum, and further incubated at 37°C for 15 min in D-MEM/F-12 (1:1) mixed medium containing 5 mM 3-isobutyl-1-methylxanthine (IBMX). In the presence of
10 10 μ M forskolin, various concentrations of histamine were added thereto and cAMP in the cells was measured after the incubation at 37°C for 15 min.

Intracellular cAMP was measured using the cyclic AMP enzymeimmunoassay (EIA) system (Amersham Pharmacia Biotech) according to the attached manual. At this time, cells were lysed with 200 μ l of Lysis buffer per well and 20 μ l of this cell extraction solution was
15 used for cAMP measurement.

As a result, in rat BG2-2-expressing cells and rat BG2-expressing cells, the decrease of intracellular cAMP concentration, dependent on histamine concentration, was confirmed in the presence of 10 μ M forskolin (Fig. 6). This indicates that both alternative splicing variants, rat BG2-2 and rat BG2 receptors, were coupled with G α i and that, specifically to
20 histamine, they reduced intracellular cAMP concentration.

Example 11: Preparation of cells expressing each BG2 (human BG2, rat BG2-2, or rat BG2)

Vectors expressing each BG2 receptor were prepared using pEF1x (Biochemical and Biophysical Research Communications, 1998, 250:68-71). Each BG2 expression vector was
25 introduced into COS7 cells by lipofection method. Genes were introduced using Lipofectamine PLUS reagent (GIBCO-BRL) according to the attached manual.

The cells were cultured at 37°C for 24 hours in Dulbecco MEM medium (Asahi Techno Glass) to which fetal calf serum (Sigma) was added at a final concentration of 10%, in an incubator in which CO₂ concentration was adjusted to 5%. Then, the cells were used
30 for preparing a membrane fraction for the histamine binding experiment.

Example 12: Histamine binding experiment for each BG2 receptor

The cells into which each BG2 receptor-expressing vector was introduced were crushed in 50 mM Tris-HCl pH 7.4 solution according to the standard method, uncrushed cells were removed by centrifuging at 1,000 g for 10 min, and supernatant was centrifuged at 100,000 g for 10 min to obtain a membrane fraction. The membrane fraction was resuspended in the 50 mM Tris-HCl pH 7.4 solution and centrifuged twice at 100,000 g for 10 min to finally obtain the membrane fraction. The membrane fraction obtained in this manner was suspended in 50 mM Tris-HCl pH 7.4 solution and used for the binding experiment.

By using N- α -methylhistamine, a histamine analogue agonist, the binding experiment was conducted and the binding constants were determined (Table 2). The above membrane fraction was warmed at 30°C for 40 min with N- α -methylhistamine (NEN) in 50 mM Tris-HCl pH 7.4 solution and the cells were collected with Unifilter plate GF/C (Packard) treated in advance with 0.5% polyethyleneimine (Wako). The nonspecific binding of the histamine analogue to cells was measured in the presence of 2 μ M N- α -methylhistamine (RBI). As a result, it was demonstrated that all cells expressing each BG2 receptor specifically bound to N- α -methylhistamine.

Table 2

Receptor	Binding Constant(nM)
Human BG2	0.548 ± 0.0751
Rat BG2	0.503 ± 0.0198
Rat BG2-2	0.582 ± 0.0261

INDUSTRIAL APPLICABILITY

The present invention has provided a human-derived novel G protein-coupled receptor protein expressed in the brain, rat-derived protein corresponding to it, and their genes. Use of the receptors makes it possible to screen their ligands and compounds that are candidates for medicines. These ligands and candidate compounds would be useful in the diagnosis and treatment of diseases arising from disorders of signal transduction pathway mediated by the G protein-coupled receptor of the invention.